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Estimation of CBR Value Using Dynamic Cone Penetrometer

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Abstract — IRC-37-2001, the Indian Roads Congress standard deals with the design of flexible pavements and recommends the California Bearing Ratio (CBR) as an indicator of subgrade soil strength. The subbase/base thickness of pavement is governed by the CBR value of the subgrade soil along with some other parameters such as traffic intensity, climatic conditions, etc. The conventional CBR testing method is expensive, time consuming and its repeatability is low. Additionally, it is very difficult to mould the sample at the desired in-situ density in the laboratory CBR test. Values of in-situ density are underestimated due to local dampness of surface water percolation and stress release while taking out the sample. Dynamic cone penetration test (DCPT) value conducted in the field can be used to estimate the CBR value provided a suitable relationship exists between CBR and DCPT value. In the present study an attempt has been made to establish a relationship between the DCPT value and the CBR.

1 INTRODUCTION

The design of new flexible pavements and rehabilitation of existing pavements need an accurate estimation of CBR value. In the design of overlays, generally Benkelman's beam method and Falling Weight Deflectometer (FWD) are used, but these methods are sophisticated and time consuming. Scala (1956) has successfully used dynamic cone penetrometer (DCP) for estimating the strength of soil. The study was mainly in relation to application in design and strengthening of existing pavements. Some work regarding correlation between DCPT and CBR has been reported in literature (Smith and Pratt 1983, Livenh 1989), but the conditions considered have not simulated the actual highway condition. During the design of new pavements or strengthening of existing ones, worst possible environmental condition to be faced by the highway during its design life should be simulated. Therefore in situ CBR tests have to be conducted after saturating the existing subgrades fully. However, it is very difficult to conduct a field soaked CBR test and is almost impractical in many situations. On the other hand in case of a laboratory CBR test, specimens after being moulded at in situ density tend to give higher values of CBR than those obtained in the field, especially for sandy soils (Haison 1987). The difference is due to the confining effect of rigid mould in laboratory tests. Again in field CBR tests, many times unrealistic values of CBR are obtained, whenever piston tip rests on a small stone particle or pebble. In view the above limitations of field as well as laboratory CBR tests, it was decided to conduct dynamic cone penetration (DCPT) tests in place of CBR tests. The DCPT test values can be used to estimate the CBR values provided a suitable relationship exists between the CBR and the DCPT value. Development of any such relationship may become very effective tool for highway engineers. The other benefits of the relationship are the following: (a) It may help enhancing highway construction quality control; (b) It may help ensuring long-term pavement performance and stability; and (c) It may help achieving more uniform structural property. In the present study, DCP tests were conducted along the 8 km long stretch of the left bank of Sidhwan canal passing through the southern part of Ludhiana city in Punjab state for widening and strengthening of the existing road. Total 8 locations were earmarked at an interval of one km after visiting the site. The interval was decided based on uniformity of soil available along the whole stretch. The present study describes a series of DCP tests conducted under in situ conditions and soaked in situ condition during monsoon. In addition to the field tests, laboratory soaked CBR tests moulded at in situ density were also carried out. In the present paper, the results obtained from the tests were presented and discussed in detail. With careful experiments, limitations of the DCP test such as blunting of cone due

to its repeated use and inadequate fall of hammer were overcome.

2 EXPERIMENTAL WORKS

The DCP tests were conducted according to the procedure laid down in ASTM-D6951-3 (2003). The apparatus consists of 16 mm diameter steel rod in which a tempered steel cone with a 20 mm base diameter and a 60 degree point angle is attached. The DCP is driven into the soil by a 8 kg hammer with a free fall of 575 mm. The hammer correction factor is unity for 8 kg hammer. Figure 1 shows the dimensions of the dynamic cone penetrometer.

The DCP test reading or dynamic cone penetration index (DCPI) is defined as the penetration depth (D) in mm for a single drop of hammer. The cone is driven into the ground up to the desired depth and average DCP index is calculated for a single blow. Depth of penetration considered in the study was 800 mm because the stresses induced due to the wheel load become negligible beyond this depth.

2.1 Field and Laboratory Tests
Following tests were conducted during the course of this study:

- Sieve analysis
- Atterberg's limit test
- Modified Procter compaction test
- In situ density test (Sand replacement method)
- Laboratory CBR test (Soaked condition at in situ density)
- Moisture content
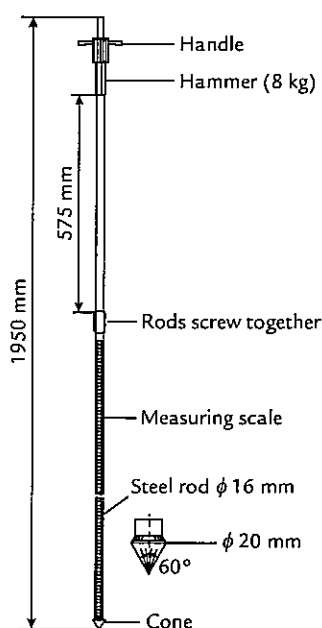- DCP test (Dry season and during monsoon)

2.2 Procedure and Sample Preparation
The experimental study involved performing a number of field and laboratory tests at different locations. To conduct soaked CBR tests at in situ density, laboratory specimens were prepared at different compaction levels by varying the number of blows. In this case four compaction levels i.e. 15, 25, 35 and 65 blows were adopted. Density and CBR values were determined for all the four cases and a graph between CBR (soaked) and density at various compaction efforts were drawn. The CBR values corresponding to the desired in-situ density were calculated from this graph. Figure 2 shows a typical variation between CBR value and dry density. Similar results were also obtained for other cases.

Dynamic cone penetration tests (DCPT) were carried out on the existing subgrade surface to determine the DCP-based CBR value at field moisture content and in-situ density. The dynamic cone penetrometer was directly placed on the subgrade and the test was started by sliding the hammer. Soil resistance was measured in terms of penetration as mm/blow. For every location three points were tested and average value was considered for the determination of CBR value. Since the imprint area of the cone tip for the first blow is smaller than that of subsequent blows, the penetration of the first blow was discounted. The number of blows was counted for 800 mm penetration of the cone and penetration per blow was calculated. To consider the effect of extreme moisture conditions, which the pavement has to face during its design life, DCP tests were conducted in dry season (April 2010) and during the monsoon (July 2010). Rest of the field and laboratory tests were conducted as per the relevant Indian Standards.

3 RESULTS AND DISCUSSION

The most important parameter to evaluate subgrade/subbase strength for the pavement design is the CBR Value. The results of various tests conducted in the
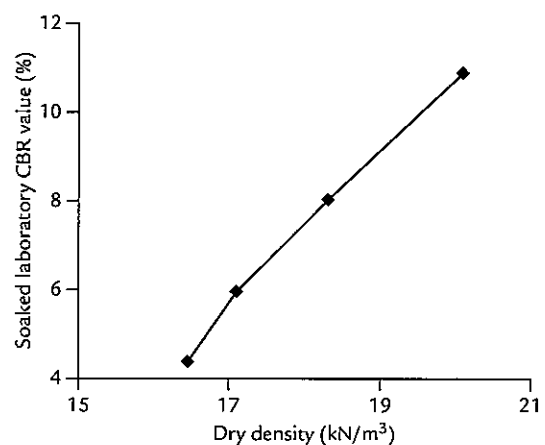

Figure 1 Dynamic cone penetrometer.

Figure 2 Soaked CBR vs. dry density.

field and laboratory are given in Table 1. It can be observed that the soil is almost uniform for all the 8 locations with sand content varying from 63.5% to 70%. Soil is non-plastic in nature with liquid limit ranging between 16.5 to 17.9%. In situ density is different for different locations varying from 16.80 to 19.20 kN/m³. In situ moisture content lies between 2.4 to 3.9%. The results in Table 2 further reveals that soaked laboratory CBR value is higher than the DCP value based on soaked in situ CBR value. This is attributed to the higher confinement pressure of rigid mould in the laboratory. The variation in CBR value under different conditions has been expressed by a dimensionless term called California bearing ratio index (CBRI) as defined by Choudhary et al. (2010). In this study variation of dynamic cone penetration index (DCPI) with moisture content and dry density has also been shown in Figures 4 and 5 respectively.

$$CBRI_1 = CBR_{LS}/CBR_{DCPS} \tag{1}$$

$$CBRI_2 = CBR_{DCP}/CBR_{DCPS} \tag{2}$$

where CBR_{LS} is the laboratory soaked CBR value at in situ density. CBR_{DCP} is DCP-based in-situ CBR value at field moisture content and in-situ density, and CBR_{DPCS} is the DCP-based in situ CBR value under soaked condition.

Figure 3 describes the variation of $CBRI_1$ and $CBRI_2$ with respect to compaction level. Compaction level has been defined as the percentage compaction in the field with respect to the maximum dry density. Variation between CBRI and compaction level can be expressed in terms of linear equations as given below for $CBRI_1$ and $CBRI_2$, respectively:

$$y = 0.0007x + 1.4646 \tag{3}$$

$$y = -0.0015x + 2.1465 \tag{4}$$

Results tabulated in Tables 1 and 2 also show the variation of CBR value with respect to dry density and moisture content in the practical application of the dynamic cone penetration approach for assessing CBR at site.

The results discussed in this study are applicable for a particular type of soil considered in this study. If the soil is different from soil tested in the present study, one should use a regression function for data obtained for various conditions of soil type, moisture content and in-situ density.

4 CONCLUSIONS

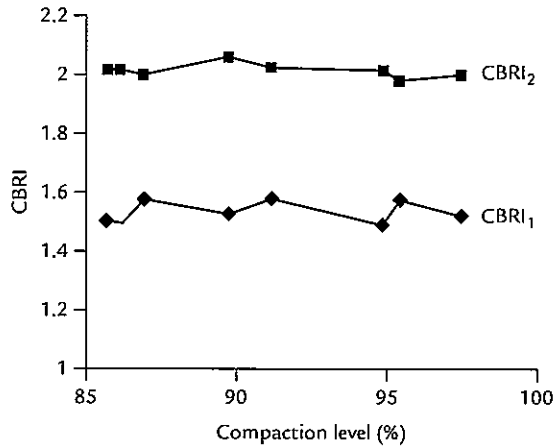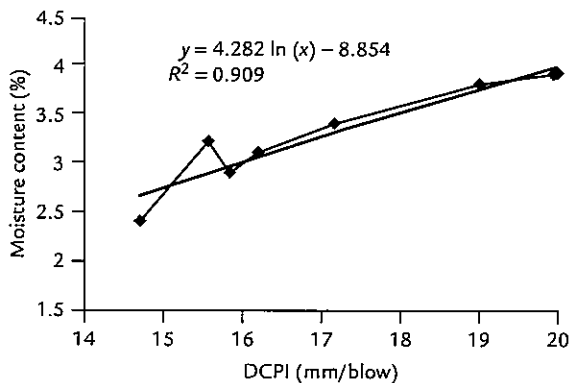Based on the study, following conclusions can be drawn.

1. The CBR value of uniform soils having similar characteristics can be determined quickly using the DCPT results.

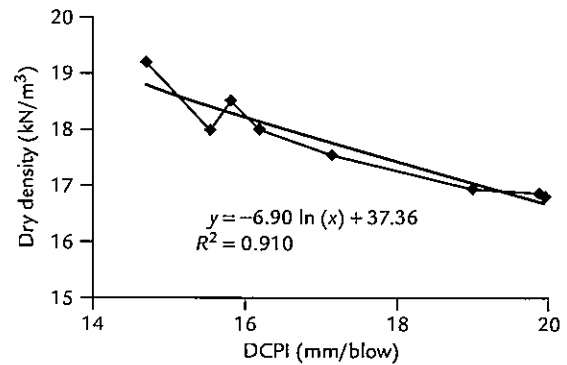**Table 1** In situ and laboratory tests at different locations

Chainage (km)	In situ dry density (kN/m³)	Field moisture content (%)	Maximum dry density (kN/m³)	Optimum moisture content (%)	Compaction level (%)	Sand content (%)	Liquid limit (%)	Plasticity index (%)
4.25	19.20	2.4	19.70	9.5	97.46	70	16.5	NP
5.25	18.80	3.2	19.70	9.5	95.43	70	16.5	NP
6.25	17.55	3.4	19.55	9.6	89.76	68.5	17.0	NP
7.25	16.95	3.8	19.50	9.6	86.92	68.0	17.0	NP
8.25	18.50	2.9	19.50	9.6	94.87	66.5	17.2	NP
9.25	18.00	3.1	19.75	9.4	91.13	64.5	17.7	NP
10.25	16.85	3.9	19.55	9.5	86.18	65.0	17.5	NP
11.25	16.80	3.9	19.60	9.5	85.71	63.5	17.9	NP

Table 2   Soaked laboratory CBR, DCPI and in situ CBR test values at different locations

Chainage (km)	Soaked laboratory CBR at in situ density (%)	In situ CBR based on DCPT (%)	Soaked in situ CBR based on DCPT(%)	DCPI (mm/blow)
4.25	10.94	14.40	7.20	14.7
5.25	10.59	13.50	6.75	15.55
6.25	8.95	12.10	5.87	17.15
7.25	8.50	10.80	5.40	19.00
8.25	9.94	13.24	6.68	15.83
9.25	10.12	12.95	6.41	16.20
10.25	7.61	10.24	5.09	19.90
11.25	7.61	10.20	5.07	19.98

Figure 3   CBRI vs. compaction level.

Figure 4   Moisture content vs. DCPI.

Figure 5   Dry density vs. DCPI.

6. The study may be helpful in enhancing highway construction quality control, ensuring long-term pavement performance, and achieving more uniform structural property.

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2. The soaked CBR value in the field can be determined very quickly by conducting the in situ DCPT for existing conditions and using the relationship between the CBRI and compaction level.

3. Laboratory CBR value can be evaluated after establishing a correlation between CBRI (CBR$_{LS}$/ CBR$_{DCPS}$) and compaction level or in situ density.

4. The relationship between moisture content, dry density and DCPI can be used to evaluate the in situ dry density and moisture content by conducting the DCPT at the site.

5. For construction of new embankments or strengthening of existing pavements, DCPT will be very useful for evaluating the strength of subgrade in terms of CBR value.